Borromean nuclei ^{6}He and ^{8}He elastic scattering with heavy targets at near-barrier energies

Ángel-Miguel Sánchez-Benítez[1], Gloria Marquínez-Durán[1], Ismael Martel[1], Krzysztof Rusek[2], Nicholas Keeley[3], Kirby Kemper[4], E587S Collaboration

(1) University of Huelva, Spain
(2) Heavy Ion Laboratory, Poland
(3) National Centre for Nuclear Physics, Poland
(4) Florida State University

Colloque GANIL 2017
Amboise

Outline

.- Introduction

.- Similarities and differences between ^{6,8}He isotopes

.- Expected behavior of the system ^{8}He+^{208}Pb in collisions at barrier energies

.- Experimental setup for the experiment E587S @ GANIL

.- Comparison of experimental differential elastic cross sections

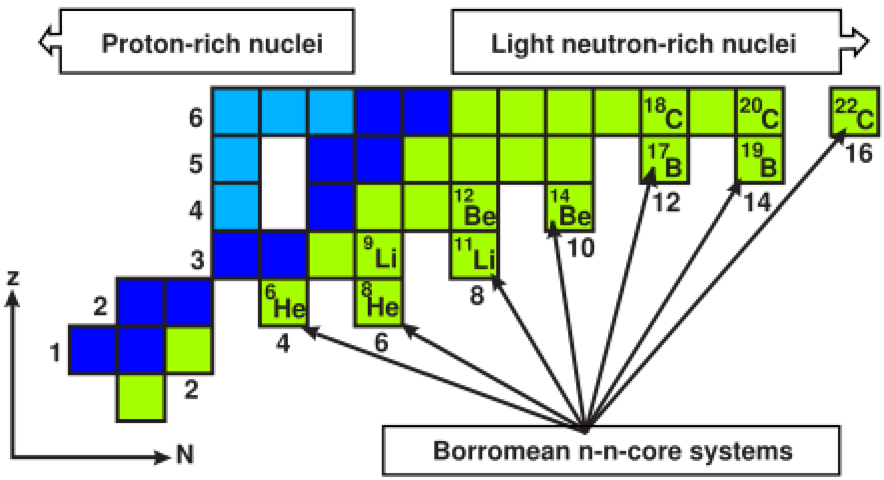
.- Long range absorption

.- Neutron(s) stripping

Introduction: ^{6,8}He isotopes knowns & expectations

.- Both systems are Borromean

Fig. from Prog. Part. Nucl. Phys. 67 (2012)939-994.
T. Frederico et al.



Introduction: ^{6,8}He isotopes knowns & expectations

.- Both systems are Borromean

.- Has the same r.m.s matter radii

Nucleus	R_n (fm)	R_p (fm)	R (fm)
^{4}He	1.63 *(0.03)*	1.63 *(0.03)*	1.63 *(0.03)*
^{6}He	2.59 *(0.04)*	1.72 *(0.04)*	2.33 *(0.04)*
^{8}He	2.69 *(0.04)*	1.76 *(0.03)*	2.49 *(0.03)*

RMS radius for neutrons, protons and total

.- Comparison of cross sections, and in particular elastic scattering will not be affected by the size of the projectile

.- Thicker neutron layer of ^{8}He may lead to weaker dipole coupling to the continuum than in the case of ^{6}He

Introduction: ^{6,8}He isotopes knowns & expectations

.- Both systems are Borromean

.- Has the same r.m.s matter radii

Nucleus	R_n (fm)	R_p (fm)	R (fm)
^{4}He	1.63 *(0.03)*	1.63 *(0.03)*	1.63 *(0.03)*
^{6}He	2.59 *(0.04)*	1.72 *(0.04)*	2.33 *(0.04)*
^{8}He	2.69 *(0.04)*	1.76 *(0.03)*	2.49 *(0.03)*

RMS radius for neutrons, protons and total

.-Both weakly bound

Nucleus	S_{1n} (keV)	S_{2n} (keV)
^{6}He	1710.0 *(20)*	974.8 *(4)*
^{8}He	2529.0 *(8)*	2125.8 *(5)*

1n and 2n energy separation

.- Comparison of cross sections, and in particular elastic scattering will not be affected by the size of the projectile

.- Thicker neutron layer of ^{8}He may lead to weaker dipole coupling to the continuum than in the case of ^{6}He

.- Long range absorption when colliding with a heavy target at barrier energies

.- ^{8}He is more bound

.- Breakup in ^{8}He < breakup in ^{6}He

Introduction: ^{6,8}He isotopes knowns & expectations

.- Both systems are Borromean

.- Has the same r.m.s matter radii

Nucleus	R_n (fm)	R_p (fm)	R (fm)
^{4}He	1.63 *(0.03)*	1.63 *(0.03)*	1.63 *(0.03)*
^{6}He	2.59 *(0.04)*	1.72 *(0.04)*	2.33 *(0.04)*
^{8}He	2.69 *(0.04)*	1.76 *(0.03)*	2.49 *(0.03)*

RMS radius for neutrons, protons and total

.-Both weakly bound

Nucleus	S_{1n} (keV)	S_{2n} (keV)
^{6}He	1710.0 *(20)*	974.8 *(4)*
^{8}He	2529.0 *(8)*	2125.8 *(5)*

1n and 2n energy separation

.- Comparison of cross sections, and in particular elastic scattering will not be affected by the size of the projectile

.- Thicker neutron layer of ^{8}He may lead to weaker dipole coupling to the continuum than in the case of ^{6}He

.- Long range absorption when colliding with a heavy target at barrier energies

.- ^{8}He is more bound

.- Breakup in ^{8}He < breakup in ^{6}He

Introduction: ^{6,8}He isotopes knowns & expectations

.- ^{6,8}He 1n and 2n-stripping in collisions with ^{208}Pb

	Q(MeV) 1n-stripping	Q(MeV) 2n-stripping
^{6}He	2.07	8.15
^{8}He	1.35	6.98

Better Q-matching for the case of ^{8}He

.- Spectroscopic factors

$<^{6}\mathrm{He}\ |^{5}\mathrm{He}+\mathrm{n}> \ -> \ 1.6$

$<^{8}\mathrm{He}\ |^{7}\mathrm{He}+\mathrm{n}> \ -> \ 2.9$

$<^{6}\mathrm{He}\ |^{4}\mathrm{He}+2\mathrm{n}> \sim \ <^{8}\mathrm{He}\ |^{6}\mathrm{He}+2\mathrm{n}> \sim 1$

Introduction: ^{6,8}He isotopes knowns & expectations

.- ^{6,8}He 1n and 2n-stripping in collisions with ^{208}Pb

	Q(MeV) 1n-stripping	Q(MeV) 2n-stripping
^{6}He	2.07	8.15
^{8}He	1.35	6.98

Better Q-matching for the case of ^{8}He

Neutron stripping should be more important for ^{8}He.

Significant coupling effects due to 1n stripping in particular should be apparent in the elastic scattering at near-barrier energies

.- Spectroscopic factors

$$<^{6}\text{He}\,|^{5}\text{He}+n> \;->\; 1.6$$
$$<^{8}\text{He}\,|^{7}\text{He}+n> \;->\; 2.9$$

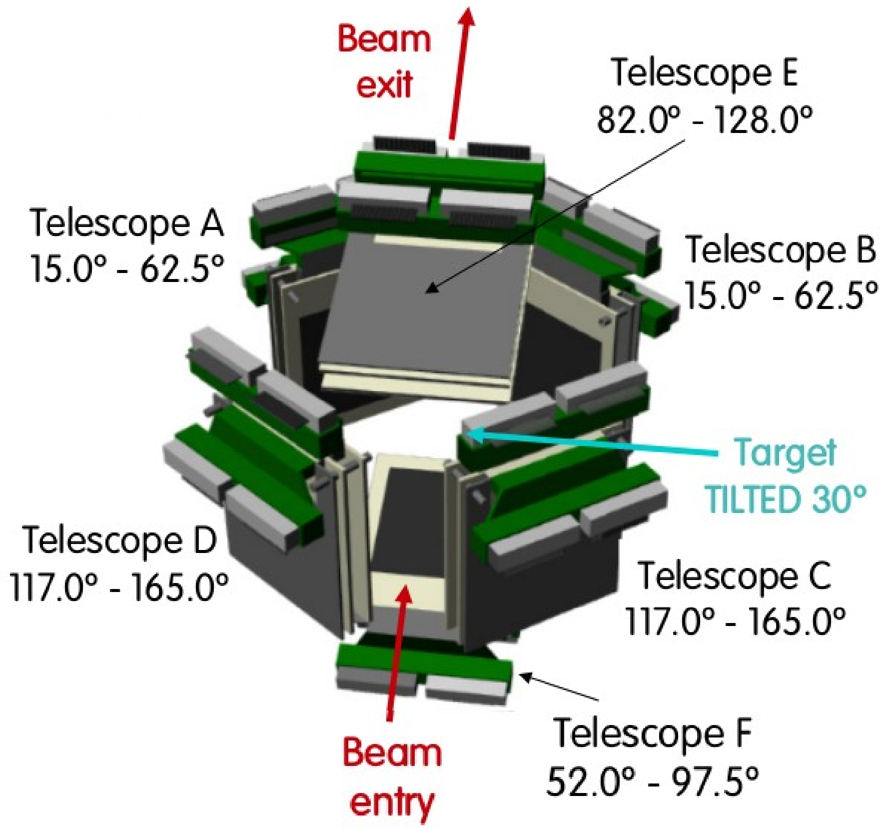
$$<^{6}\text{He}\,|^{4}\text{He}+2n> \sim\; <^{8}\text{He}\,|^{6}\text{He}+2n> \sim 1$$

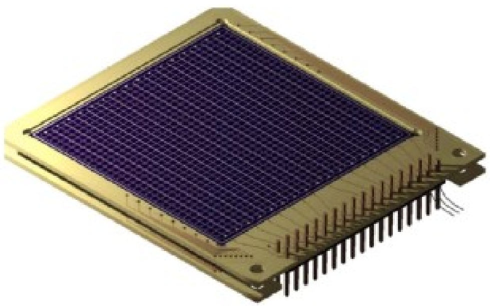
E587S @ GANIL experimental setup

Detection system developed as part of this work with the aim of studying the structure and dynamics of exotic nuclei using nuclear reactions.

Design requirements:

* Symmetric position of telescopes
* Maximum angular range
* Angular range overlap
* Large solid angle





O. Tengblad et al., Nucl. Instr. and Meth. Phys. Res. A525 (2004) 458.

12 DSSSD detectors arranged in 6 particle telescopes

First stage (ΔE) 40 μm, Second stage (E) 1 mm

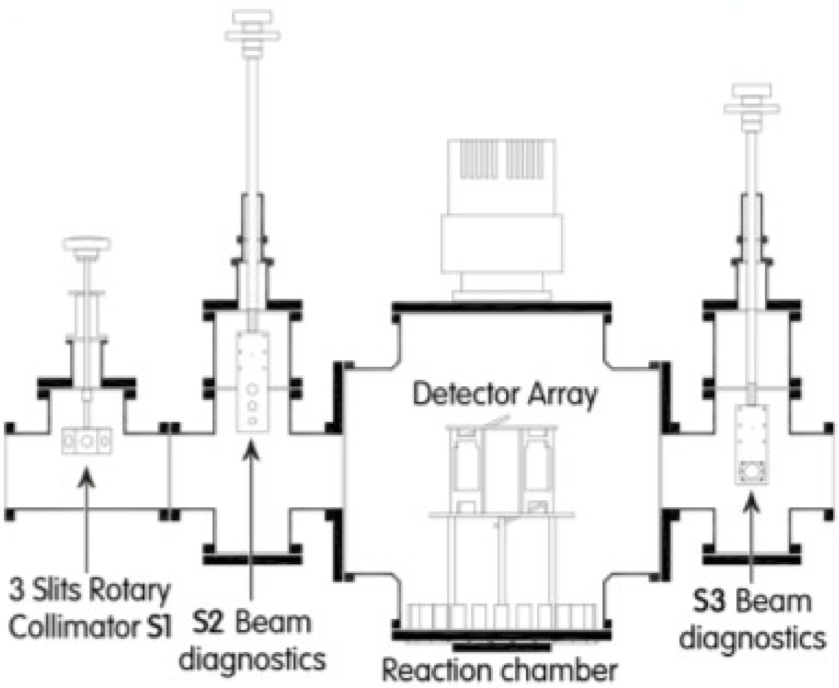
Total solid angle for the system: **26% (4π)**

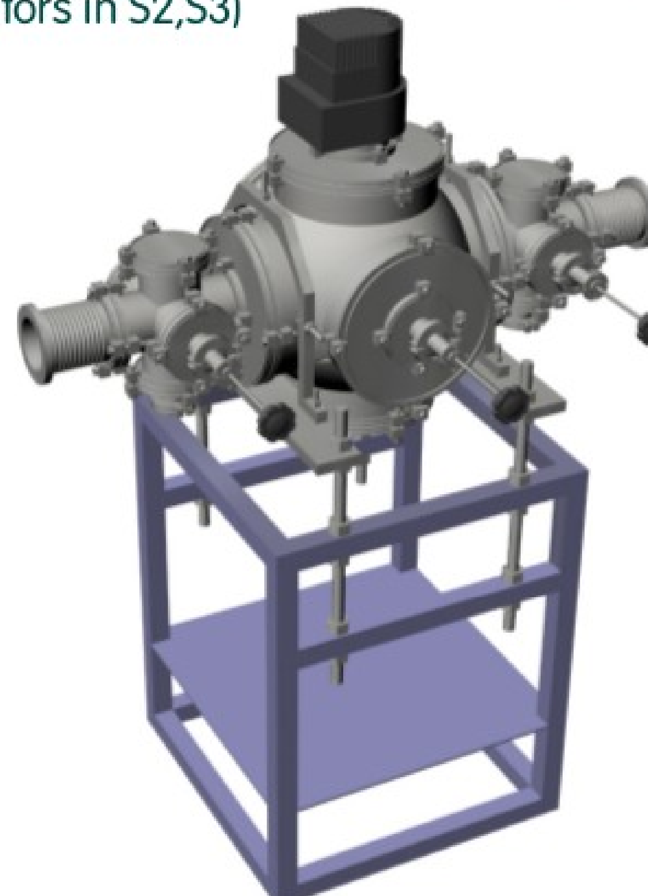
E587S @ GANIL beam diagnostics

* Reaction chamber 250∅ LF (10^{-7} mbar)

* Collimator and diagnostic systems → optimize transmission and focusing on target

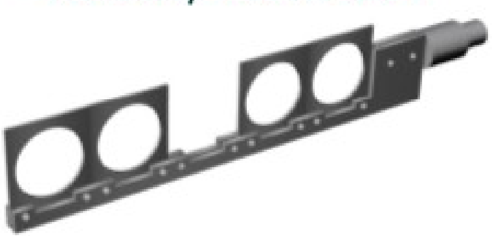
* S1, S2 and S3 → frame with several circular collimating holes of different sizes (+ faraday cup in and PIP detectors in S2,S3)

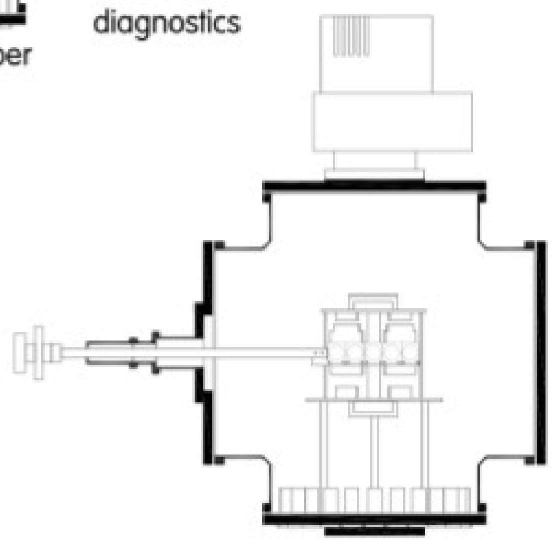




TARGET HOLDER:

* Linear movement
* Rotatory movement





SIDE VIEW

Absorption of elastic flux

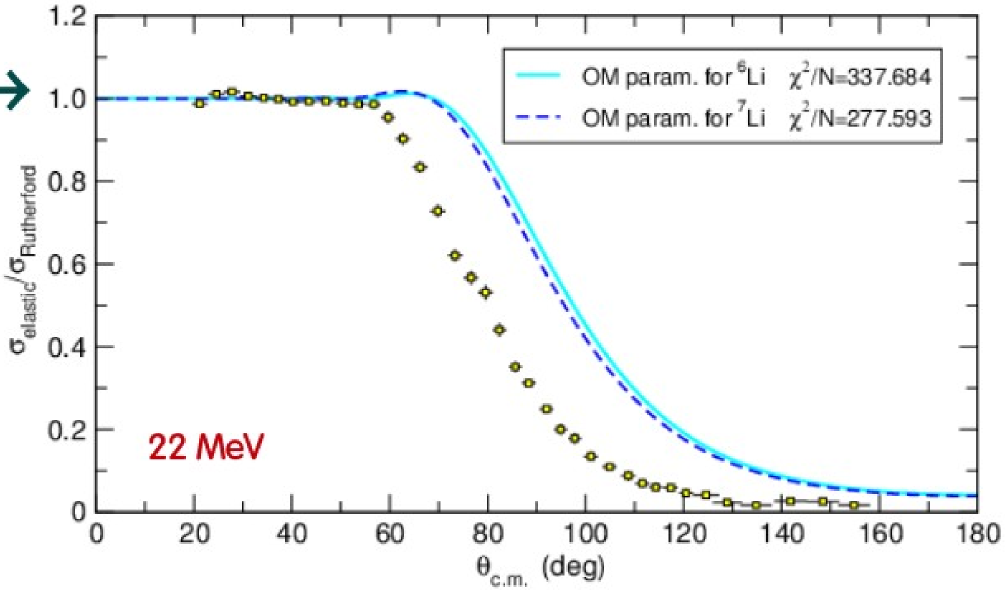
$^{8}He+^{208}Pb$ @ E_{Lab}=22 MeV

Comparison with previous phenomenological potentials for $^{6,7}Li$ *(J. Cook, Nucl. Phys. A388 (1982) 153)*

	V_o	r_R	a_R	W_o	r_I	a_I
^{6}Li	109.5	1.326	0.811	22.4	1.534	0.884
^{7}Li	114.2	1.286	0.853	9.4	1.739	0.809

$$V(r)=\frac{-V_o}{1+\exp(\frac{r-r_R}{a_R})} \qquad W(r)=\frac{-W_o}{1+\exp(\frac{r-r_I}{a_I})}$$

→



Absorption of elastic flux

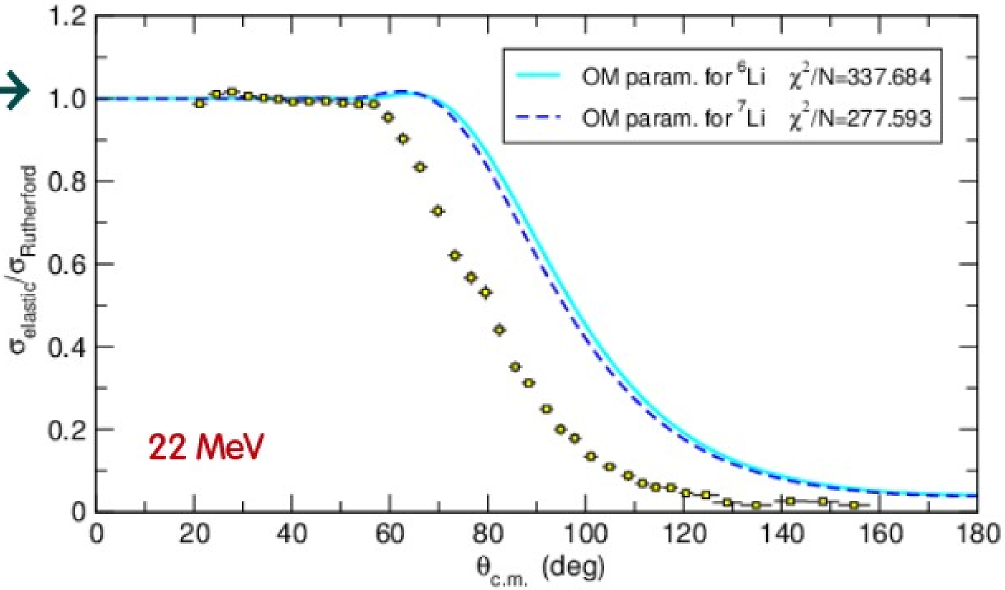
$^{8}He+^{208}Pb$ @ E_{Lab}=22 MeV

Comparison with previous phenomenological potentials for ^{6,7}Li *(J. Cook, Nucl. Phys. A388 (1982) 153)*

→

	V_o	r_R	a_R	W_o	r_I	a_I
^{6}Li	109.5	1.326	0.811	22.4	1.534	0.884
^{7}Li	114.2	1.286	0.853	9.4	1.739	0.809

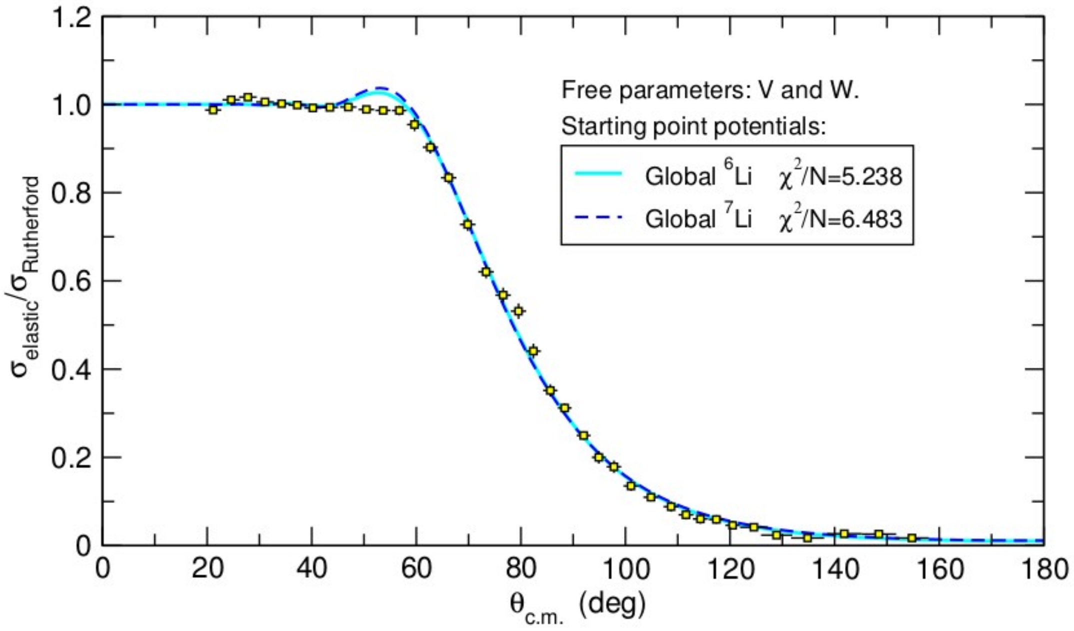
$$V(r)=\frac{-V_o}{1+\exp\left(\frac{r-r_R}{a_R}\right)} \qquad W(r)=\frac{-W_o}{1+\exp\left(\frac{r-r_I}{a_I}\right)}$$



Systematics from stable nuclei do not reproduce data of ^{8}He

Absorption of elastic flux

^{8}He+^{208}Pb @ E_{Lab}=22 MeV

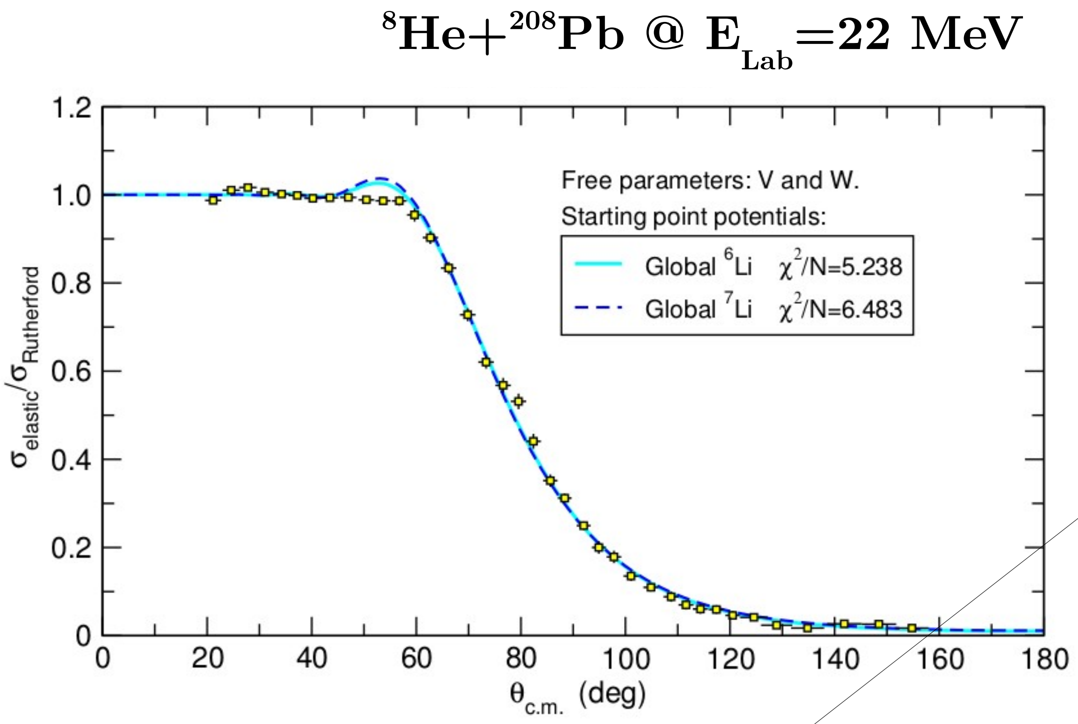


Fit with the same geometry (V, W free)

Starting point	V(MeV)	W(MeV)	χ^2 /N
^{6}Li global parameters	337.26	118.15	5.24
^{7}Li global parameters	366.58	45.55	6.48

	V_o	r_R	a_R	W_o	r_I	a_I
^{6}Li	109.5	1.326	0.811	22.4	1.534	0.884
^{7}Li	114.2	1.286	0.853	9.4	1.739	0.809

Absorption of elastic flux



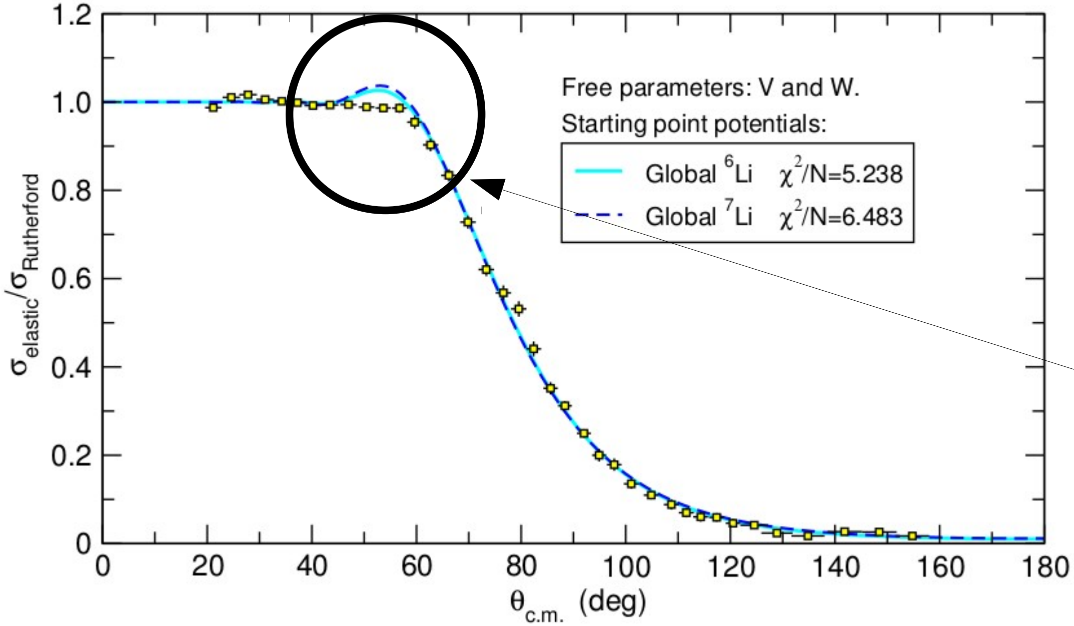
Fit with the same geometry (V, W free)
- More absorption

Starting point	V(MeV)	W(MeV)	χ^2 /N
^{6}Li global parameters	337.26	118.15	5.24
^{7}Li global parameters	366.58	45.55	6.48

	V_o	r_R	a_R	W_o	r_I	a_I
^{6}Li	109.5	1.326	0.811	22.4	1.534	0.884
^{7}Li	114.2	1.286	0.853	9.4	1.739	0.809

Absorption of elastic flux

^{8}He+^{208}Pb @ E$_{Lab}$=22 MeV



Fit with the same geometry (V, W free)

- More absorption

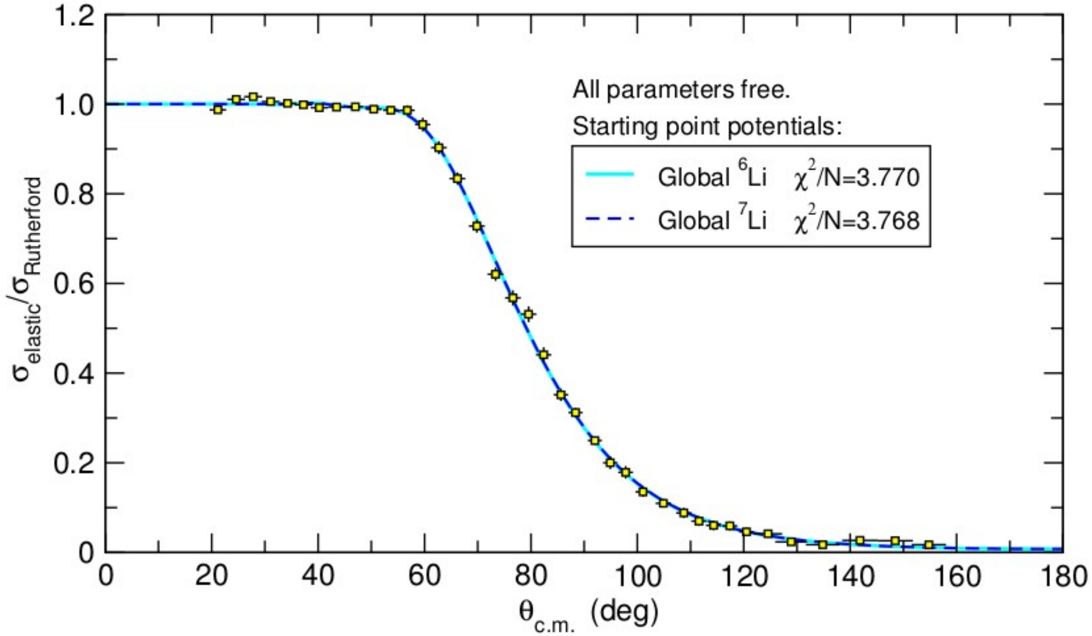
- Still rainbow

Starting point	V(MeV)	W(MeV)	χ^2 /N
^{6}Li global parameters	337.26	118.15	5.24
^{7}Li global parameters	366.58	45.55	6.48

	V_o	r_R	a_R	W_o	r_I	a_I
^{6}Li	109.5	1.326	0.811	22.4	1.534	0.884
^{7}Li	114.2	1.286	0.853	9.4	1.739	0.809

Absorption of elastic flux

$^8He+^{208}Pb$ @ E_{Lab}=22 MeV

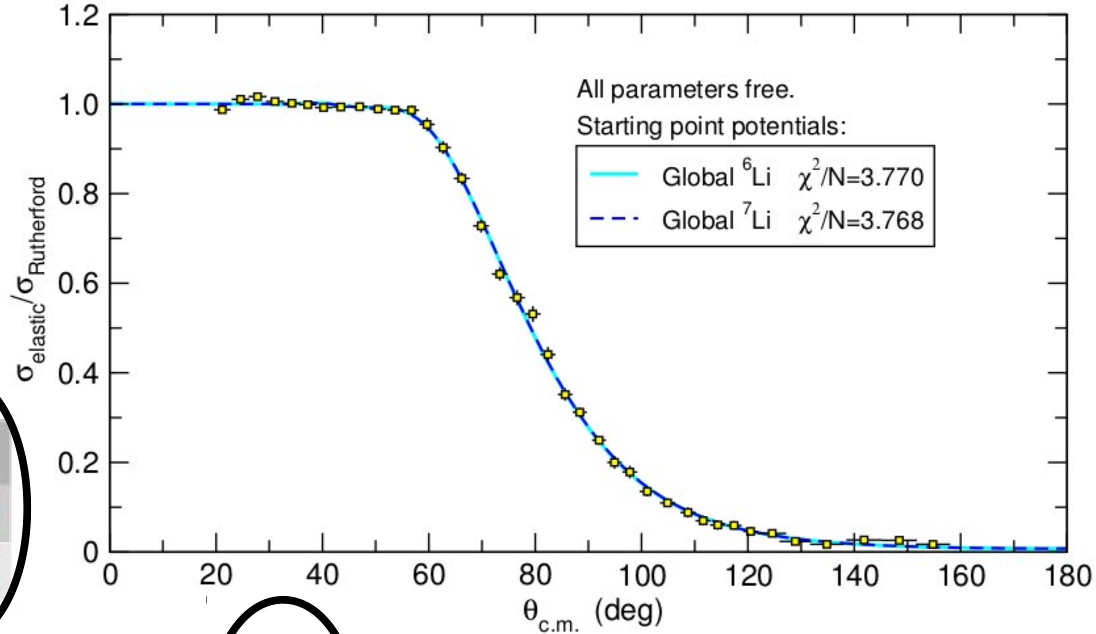


Starting point	V	r_R	a_R	W	r_I	a_I	χ^2/N
^{6}Li global	109.78	1.667	0.577	22.51	1.581	1.144	3.77
^{7}Li global	113.46	1.657	0.583	33.51	1.501	1.147	3.77

Fit with six parameter free

Absorption of elastic flux

^{8}He+^{208}Pb @ E_{Lab}=22 MeV



	V_o	r_R	a_R	W_o	r_I	a_I
^{6}Li	109.5	1.326	0.811	22.4	1.534	0.884
^{7}Li	114.2	1.286	0.853	9.4	1.739	0.809

Starting point	V	r_R	a_R	W	r_I	a_I	χ^2/N
^{6}Li global	109.78	1.667	0.577	22.51	1.581	1.144	3.77
^{7}Li global	113.46	1.657	0.583	33.51	1.501	1.147	3.77

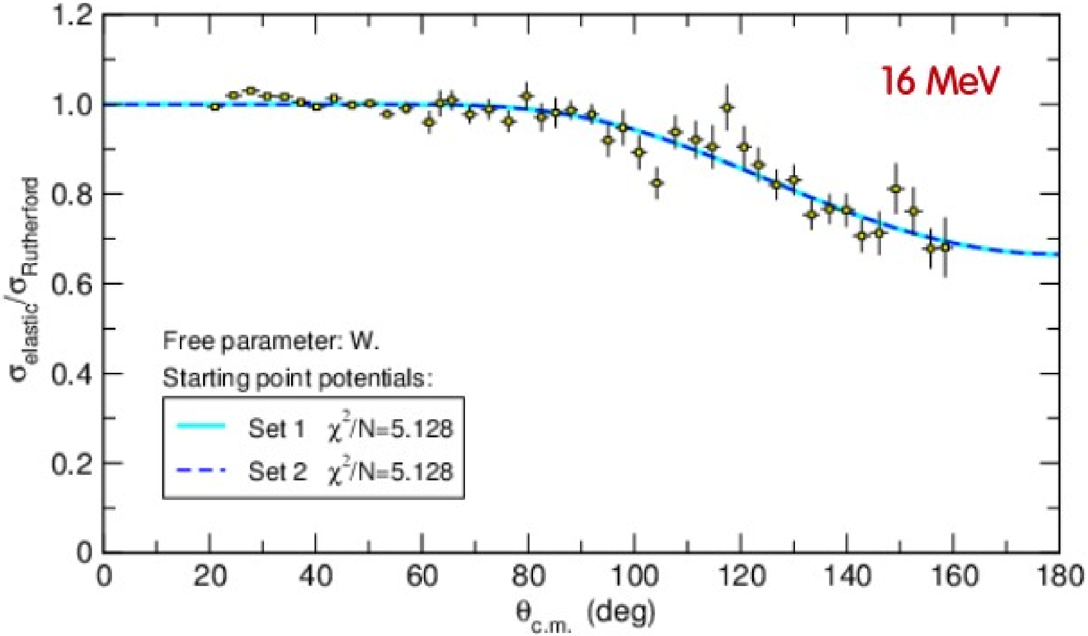
Larger values for the imaginary diffusenesses, responsible for the absorption of flux from the elastic channel:

* Existence of **long-range mechanisms**

* **Vanishing** of the Coulomb-nuclear **rainbow**

Absorption of elastic flux

$^{8}He+^{208}Pb$ @ E_{Lab}=16 MeV



Geometry of the potentials fixed for 22 MeV → Search on V and W for 16 MeV

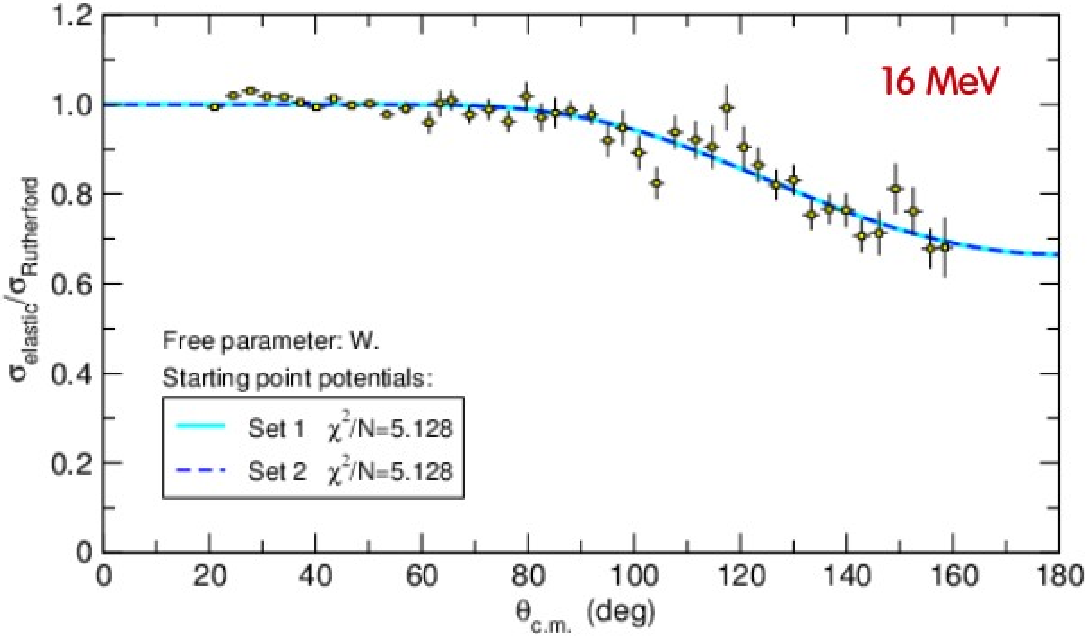
	V_o	r_R	a_R	W_o	r_I	a_I
^{6}Li global	109.8	1.667	0.577	29.7	1.581	1.144
^{7}Li global	113.5	1.657	0.583	44.2	1.501	1.147

W	
22.51	@ 22 MeV
33.51	

Unlike ^{6}He in *A.M. Sánchez-Benítez et al., Nucl. Phys. A803 (2008) 30* → **W (16 MeV) > W (22 MeV)** → already observed for ^{6}Li in *N. Keeley et al., Nucl. Phys. A571 (1994) 326.*

Absorption of elastic flux

$^{8}He+^{208}Pb$ @ E_{Lab}=16 MeV



Might be due to breakup effects still present at sub-barrier energies??

Geometry of the potentials fixed for 22 MeV → Search on V and W for 16 MeV

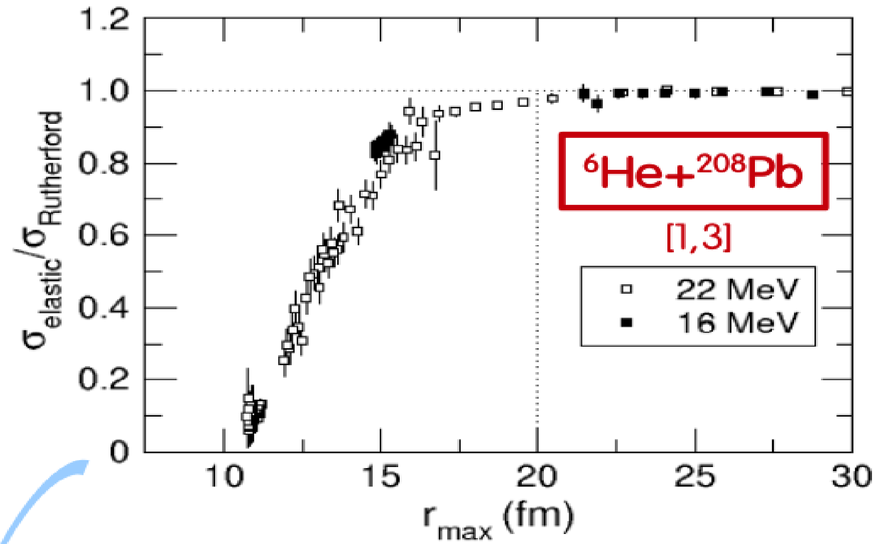
	V_o	r_R	a_R	W_o	r_I	a_I
^{6}Li global	109.8	1.667	0.577	29.7	1.581	1.144
^{7}Li global	113.5	1.657	0.583	44.2	1.501	1.147

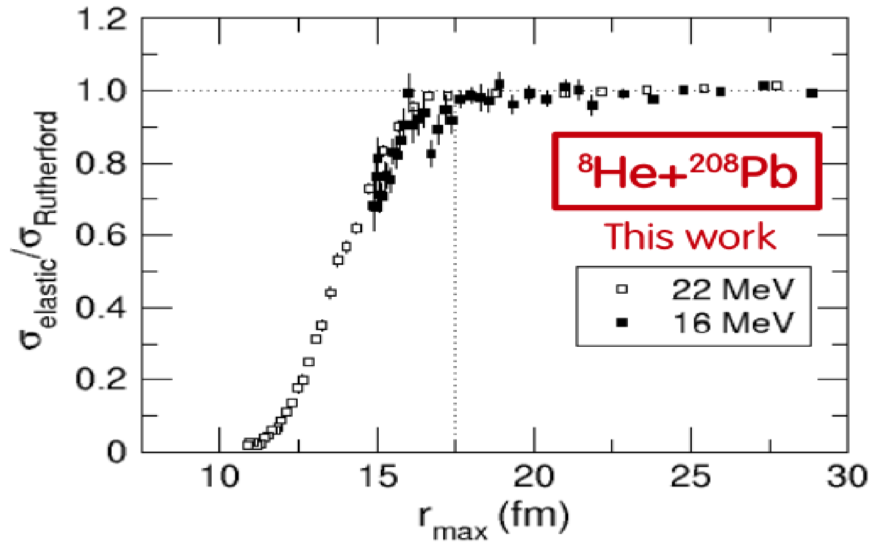
W	
22.51	@ 22 MeV
33.51	

Unlike ^{6}He in *A.M. Sánchez-Benítez et al., Nucl. Phys. A803 (2008) 30* → **W (16 MeV) > W (22 MeV)** → already observed for ^{6}Li in *N. Keeley et al., Nucl. Phys. A571 (1994) 326.*

Absorption of elastic flux in ^{6,8}He: range of distances

a_i ^{8}He (~ 1.2 fm) { > stable nuclei; < halo ^{6}He (a_i = 1.89 fm) } → Behaviour of ^{6}He will differ from Rutherford at distances > ^{8}He





[1] A.M. Sánchez-Benítez et al., Nucl. Phys. A803 (2008) 30
[3] L. Acosta et al., Phys. Rev. C84 (2011)044604

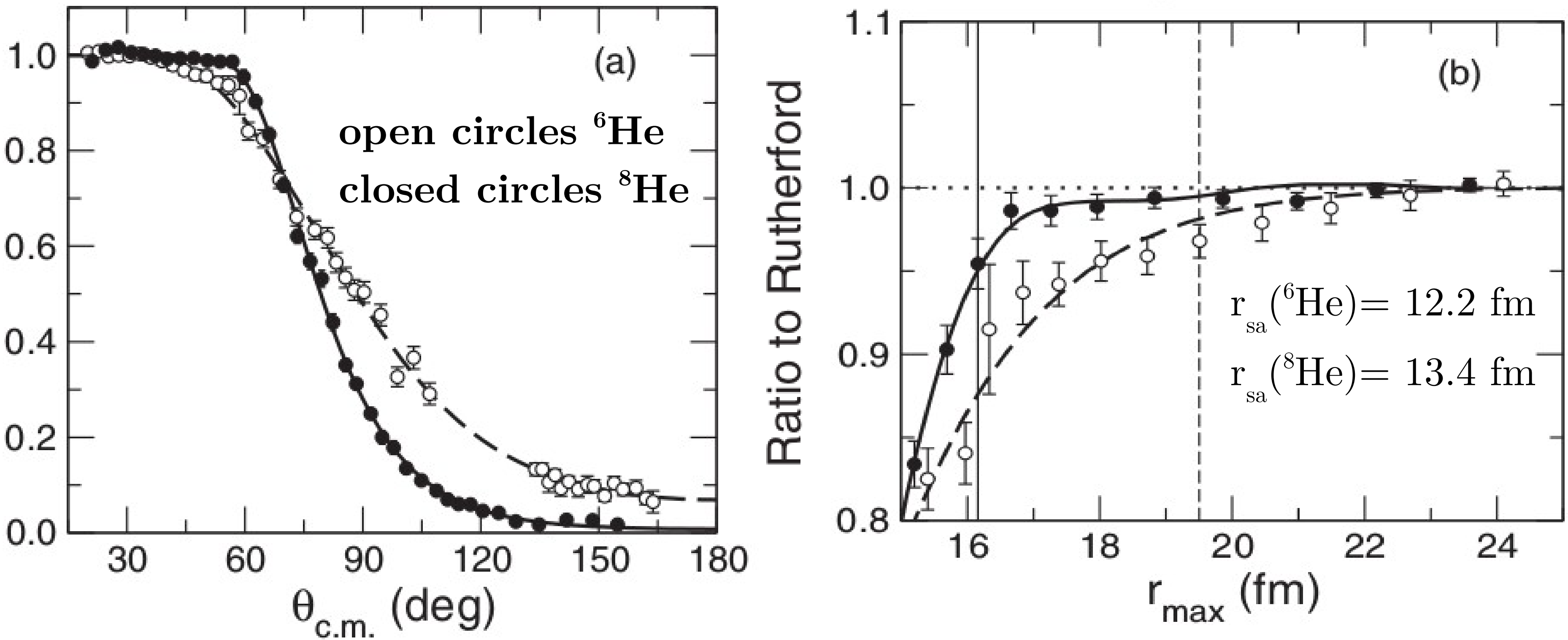
$$r_{max} = \frac{d_o}{2}\left(1 + \frac{1}{\sin(\theta/2)}\right)$$

d_o: head-on collision

Common trend for various energies:
"universal function" describing elastic scattering → Systematic behaviour also found for ^{8}He

Absorption of elastic flux in ^{6,8}He: range of distances

^{6,8}He+^{208}Pb @ E_{Lab}=22 MeV



PRC 94(2016)064618 G. Marquínez-Durán et al.

r_{max}: distance of closest approach in a classical Coulomb trajectory

Due to highly accurate measurements:

Model independent confirmation of absorption in ^{6}He occurs at larger distances than for ^{8}He

Neutron stripping in ^{6}He and ^{8}He

PRC 94(2016)064618 G. Marquínez-Durán et al.

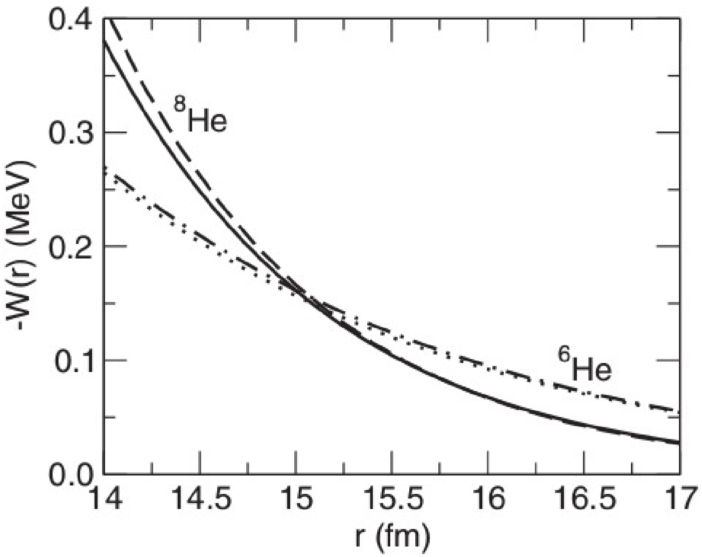


TABLE I. Optical model parameters fitting the 22 MeV ^{8}He and ^{6}He + ^{208}Pb elastic scattering data. Radii follow the convention $R_i = r_i \times A_t^{1/3}$ fm and $r_C = 1.3$ fm.

Projectile	V	r_V	a_V	W	r_W	a_W	σ_R (mb)	χ^2/N
^{8}He	157.1	1.651	0.557	10.5	1.733	1.137	1520	3.76
^{6}He	114.2	1.286	0.632	9.44	1.247	1.865	1459	0.91

^{6,8}He+^{208}Pb @ 22 MeV

.- W(^{6}He) less absorptive than W(^{8}He)

$\sigma_R(^{6}\text{He}) < \sigma_R(^{8}\text{He})$

.- W(^{6}He) more diffuse than W(^{8}He)

Coul. breakup (^{6}He) > Coul. breakup (^{8}He)

.- $\sigma_{fus}(^{6}\text{He}) \sim \sigma_{fus}(^{8}\text{He})$ (fusion)

Neutron stripping in ^{6}He and ^{8}He

PRC 94(2016)064618 G. Marquínez-Durán et al.

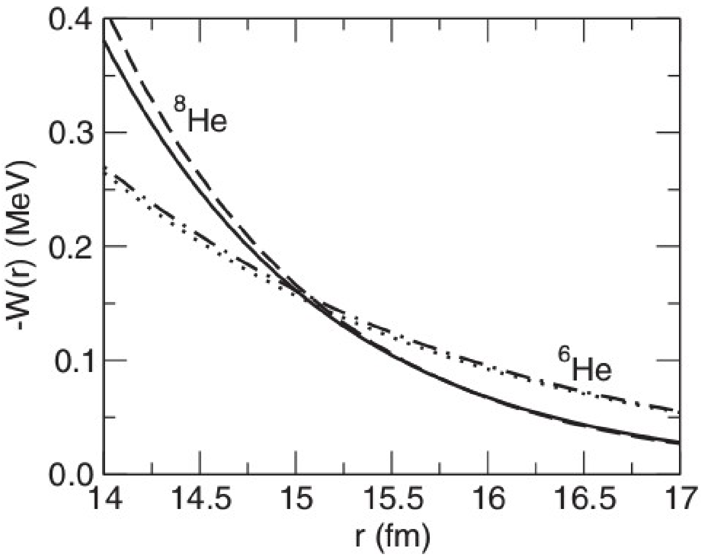


TABLE I. Optical model parameters fitting the 22 MeV ^{8}He and ^{6}He + ^{208}Pb elastic scattering data. Radii follow the convention $R_i = r_i \times A_t^{1/3}$ fm and $r_C = 1.3$ fm.

Projectile	V	r_V	a_V	W	r_W	a_W	σ_R (mb)	χ^2/N
^{8}He	157.1	1.651	0.557	10.5	1.733	1.137	1520	3.76
^{6}He	114.2	1.286	0.632	9.44	1.247	1.865	1459	0.91

^{6,8}He+^{208}Pb @ 22 MeV

.- W(^{6}He) less absorptive than W(^{8}He)

$\sigma_R(^{6}\mathrm{He}) < \sigma_R(^{8}\mathrm{He})$

.- W(^{6}He) more diffuse than W(^{8}He)

Coul. breakup (^{6}He) > Coul. breakup (^{8}He)

.- $\sigma_{fus}(^{6}\mathrm{He}) \sim \sigma_{fus}(^{8}\mathrm{He})$ (fusion)

In collisions ^{6,8}He+^{208}Pb
at barrier energies
(~ 20 MeV)
Neutron stripping
^{8}He >> ^{6}He

Summary and outlook

.- The experiment E587S to study the elastic scattering and reaction channels of ^{6,8}He+^{208}Pb @ 16, 22 MeV, bellow and around the Coulomb barrier, was successfully performed in GANIL.

.- The detector GLORIA was used for the first time with a radioactive beam, showing excellent performances in terms of portability, energy resolution and particle identification.

.- Due to the high quality of the elastic data, it is apparent in a model independent basis that absorption mechanisms takes place at longer distances for ^{6}He than ^{8}He.

.- In the framework of the Optical Model, the previous point is confirmed and the resulting reaction cross sections suggest the neutron stripping mechanism to be stronger in the case of ^{8}He.

.- Angular distribution for the ratio ^{6}He/^{8}He and ^{4}He/^{8}He are to be interpreted in the context of breakup and neutron stripping but the structure of ^{8}He makes the calculation complex.

Link to Gloria Marquínez Durán's PhD. dissertation

http://rabida.uhu.es/dspace/handle/10272/12397

ARIAS MONTANO REPOSITORY @ Univ. of Huelva

PUBLIC ACCESS !!

Thank you for your attention !!